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CHARACTERISTICS OF THE GENERAL CIRCULATION OVER THE NORTHERN HEMISPHERE DURING THE ABNORMAL WINTER 1946–47

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The Winter of 1946–47 was notable for its large variation from normal in many parts of the world. Especially was this true in Great Britain where the climate became continental rather than the normal maritime. In eastern Canada unusually mild maritime air reigned where normally the Winter has a continental regime. Northwestern Canada and Alaska experienced abnormal frigidity, while in the United States extensive mildness prevailed in December and January, giving way to severe winter cold in February. The circulation of air masses which accompanied these abnormal weather regimes made it necessary for aviators to reckon with extraordinary wind velocities on air routes over the oceans. Over the Atlantic, east-to-west crossings were made in fast time in February and March north of 50° N. latitude; in latitudes farther south, eastward crossings were rapid. These weather anomalies and many others which highlighted the winter of 1946–47 seemed to overthrow the classical model of the general circulation in the Northern Hemisphere. It is the purpose of this report to describe and investigate the nature of the anomalies and to offer a possible physical explanation of their evolution.

DESCRIPTION OF CIRCULATION AND ASSOCIATED WEATHER ANOMALIES

The monthly mean charts of sea level pressure and departure from normal for January and February are shown in Figures 1 and 2. To a considerable degree December (not reproduced) resembled January, while March (not reproduced) was similar to February. Insets in these figures show the complete Northern Hemisphere pressure profiles and the corresponding normal profiles. In the chart for February the net geostrophic zonal wind components for the hemisphere from 20° to 90° N. lat. are also shown (see inset).

The striking features of the January chart are:

1. The westward intrusion of the Siberian High into Europe (+17 mb. anomaly over Scandinavia).
2. The absence of the normal low pressure trough and storm track from the Icelandic Low northeastward, and, instead, the trough from the intense Icelandic Low through Davis Strait into the Polar Basin.
3. The imprisonment of the North American Polar Continental anticyclone in northwest Canada and the resultant domination of the United States by Pacific air masses and the Great Basin anticyclone.
4. The weakness of the western cell of the Aleutian Low.

On the corresponding chart for February (Figure 2) the following features, amazingly different from January, can be noted:

1. The tremendous extent of the Arctic High, resulting in a vast excess pressure anomaly over areas north of latitude 55° N.
2. The southward displacement of the subpolar lows, especially in the Atlantic.

The pressure profiles focus attention on the large differences in the mass of air between January and February. In February, for example, it will be observed that the belt of polar east winds normally found north of 62° N. latitude extended to 45° N. latitude (see wind profile inset, Figure 2). Correspondingly, the zonal westerlies of temperate latitudes and the subtropical easterlies were displaced far south of their normal positions.

The monthly mean 700-mb. charts for January and February are shown in Figures 3 and 4, with observed and normal height profiles inset. Further discussion of these charts will be given later, but the excess anomaly of mass at higher latitudes in February and the associated reversal of the normal upper-level polar westerlies to easterlies should be noted.

The association of the foregoing charts with the abnormal weather regimes pointed out earlier in this report now becomes clear. A simplified picture of the January and February temperature anomaly of the lower troposphere (sea level to 700 mb.) is presented in Figures 5 and 6. For the area from 0° westward to 180° W. longitude, from which fairly reliable data are available, Figures 5 and 6 are based on computed thickness anomalies for the layer from 1,000 mb. to 700 mb. For the remainder of the hemisphere they are based upon a less objective evaluation of the temperature anomaly of the lower troposphere as it would presumably be influenced by the circulation patterns and their anomalies. True charts of temperature anomalies for the entire hemisphere would be difficult, if not impossible, to prepare. For the general purposes of this report, Figures 5 and 6 are adequate.

The January flow pattern at 700 mb. (Figure 3) shows two areas of strong confluence [1] where cold Arctic air was advected beside warm tropical air. In the extreme eastern Pacific, Alaskan air with temperatures originally averaging −25° C. to −30° C. was forced to converge in the zonal westerlies with warm Pacific air from east of the Hawaiian Islands, with temperature originally averaging +5° C. The confluence of these radically different air streams, effected by the trough's position in the Gulf of Alaska north of the eastern Pacific ridge, concentrated the energy of the westerlies in a strong, narrow jet-stream whose momentum carried on downstream for some distance. This jet-stream was revitalized in eastern North America where cold air from northwest Canada flowed beside warm air originally from the States bordering on the Gulf of Mexico. The momentum of the strong westerlies continued on through the Atlantic. In view of these fast westerlies over North America, it is not surprising that the

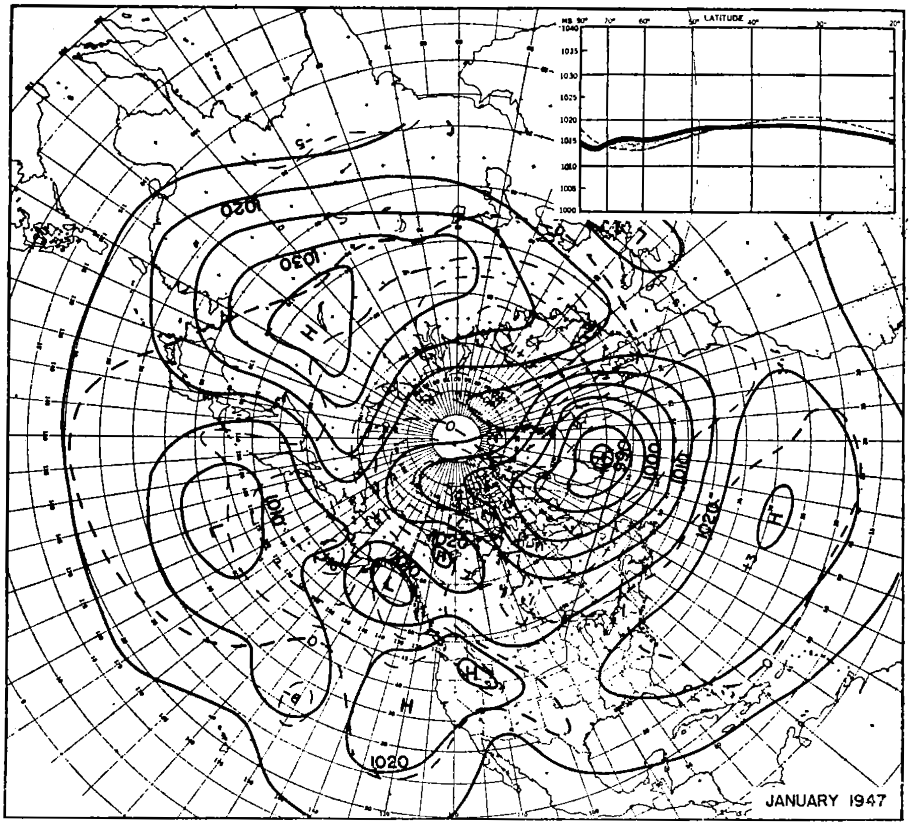

FIGURE 1.—Mean sea level chart showing isobars (solid lines) and pressure departures from normal (broken lines) for January 1947. (Inset shows observed pressure profile—solid line—and normal profile for that month, with excess anomalies shaded.)

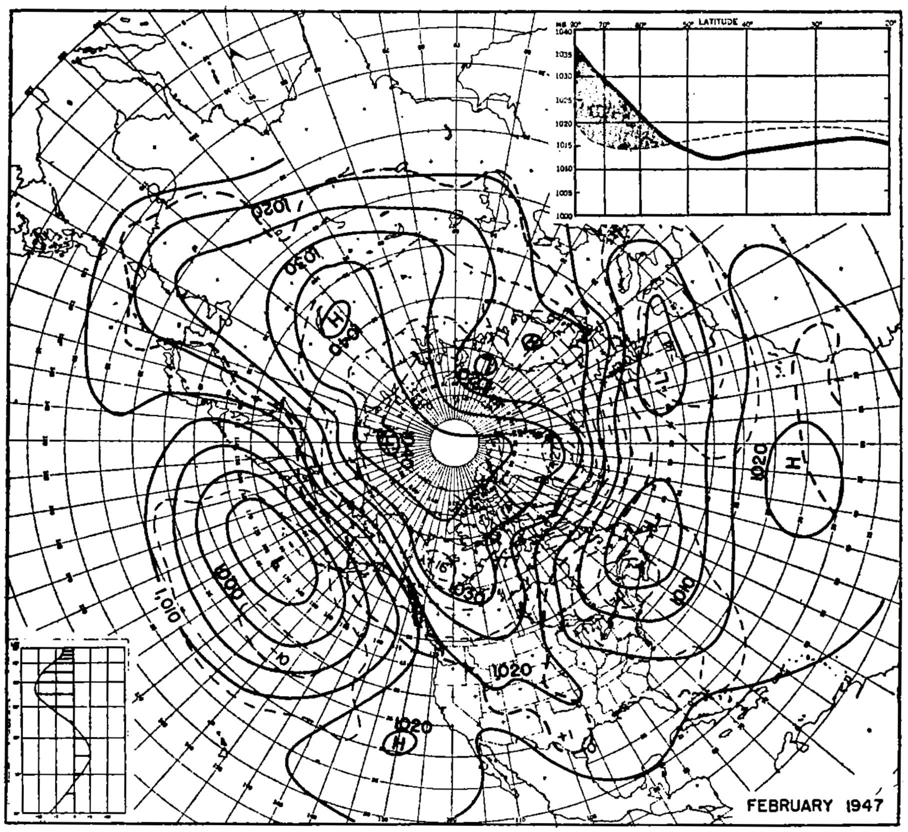

FIGURE 2.—Mean sea level chart showing isobars (solid lines) and pressure departures from normal (broken lines) for February 1947. (Inset on upper right shows observed pressure profile—solid line—and normal profile for that month, with excess anomalies shaded. Inset in lower left shows net geostrophic zonal wind components from 20°-90° N. lat.)

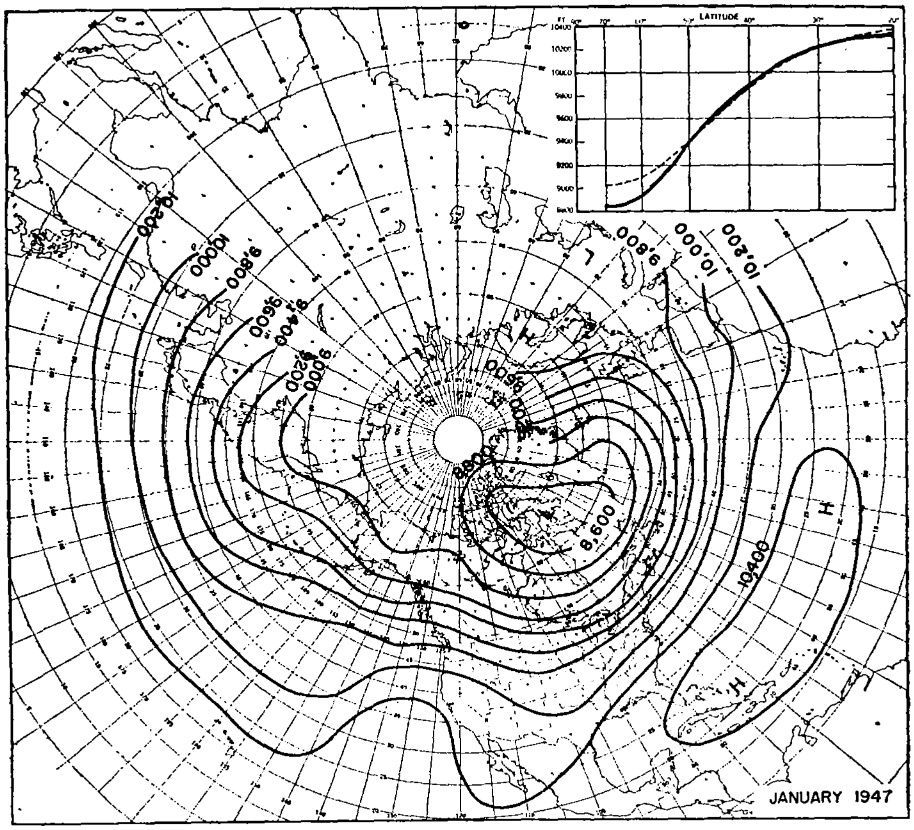

FIGURE 3.—Mean 700-mb. height contours for January 1947. (Inset shows observed height profile—solid line—and normal profile for that month, with excess anomalies shaded.)

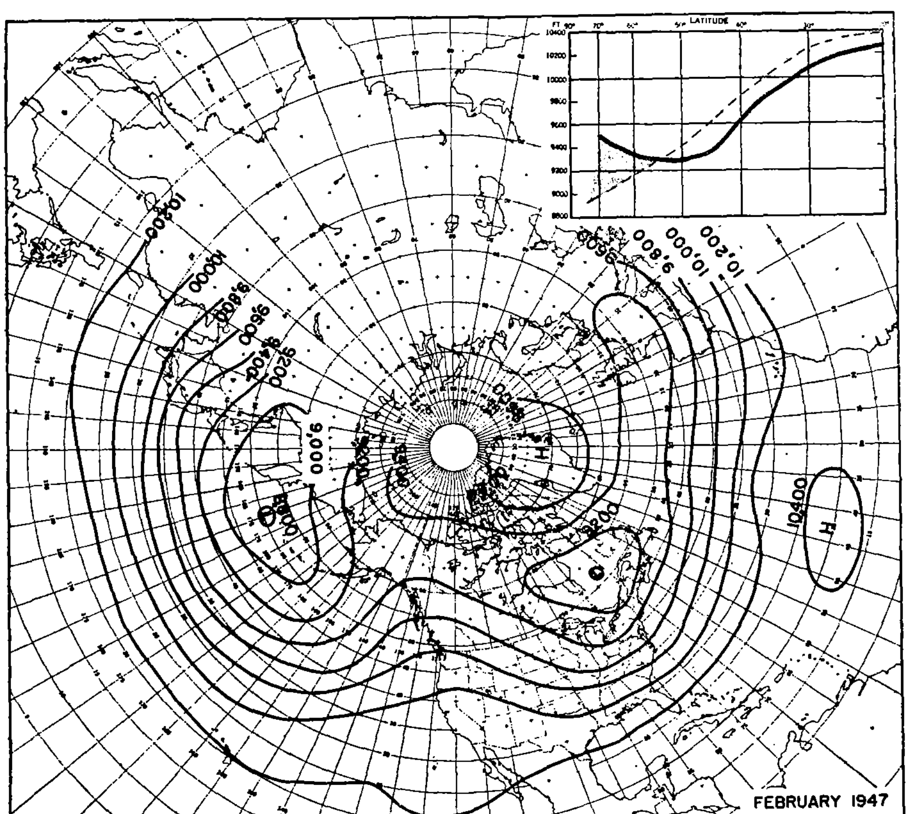

FIGURE 4.—Mean 700-mb. height contours for February 1947. (Inset shows observed height profile—solid line—and normal profile for that month, with excess anomalies shaded.)

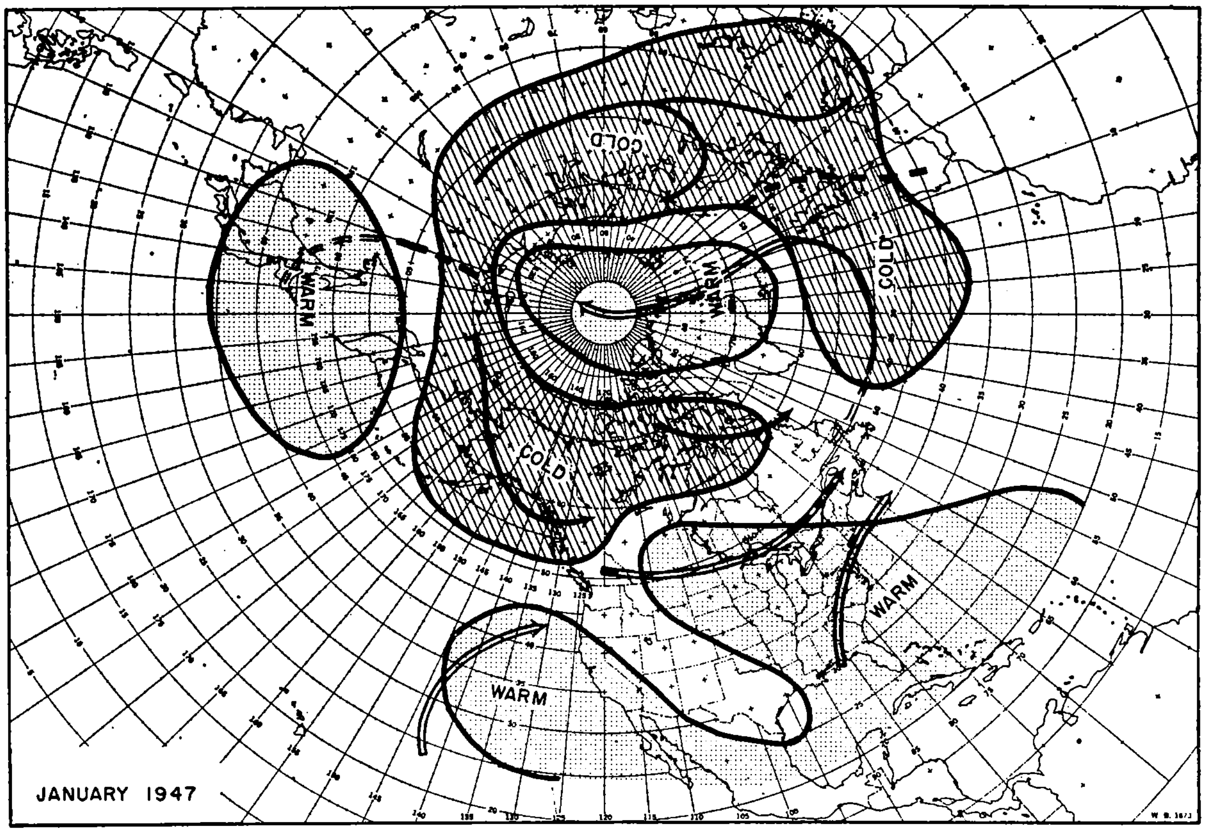

FIGURE 5.—General indicated temperature anomalies of the lower troposphere, 1,000 mb., to 700 mb., during January 1947. (Arrows indicate flow.)

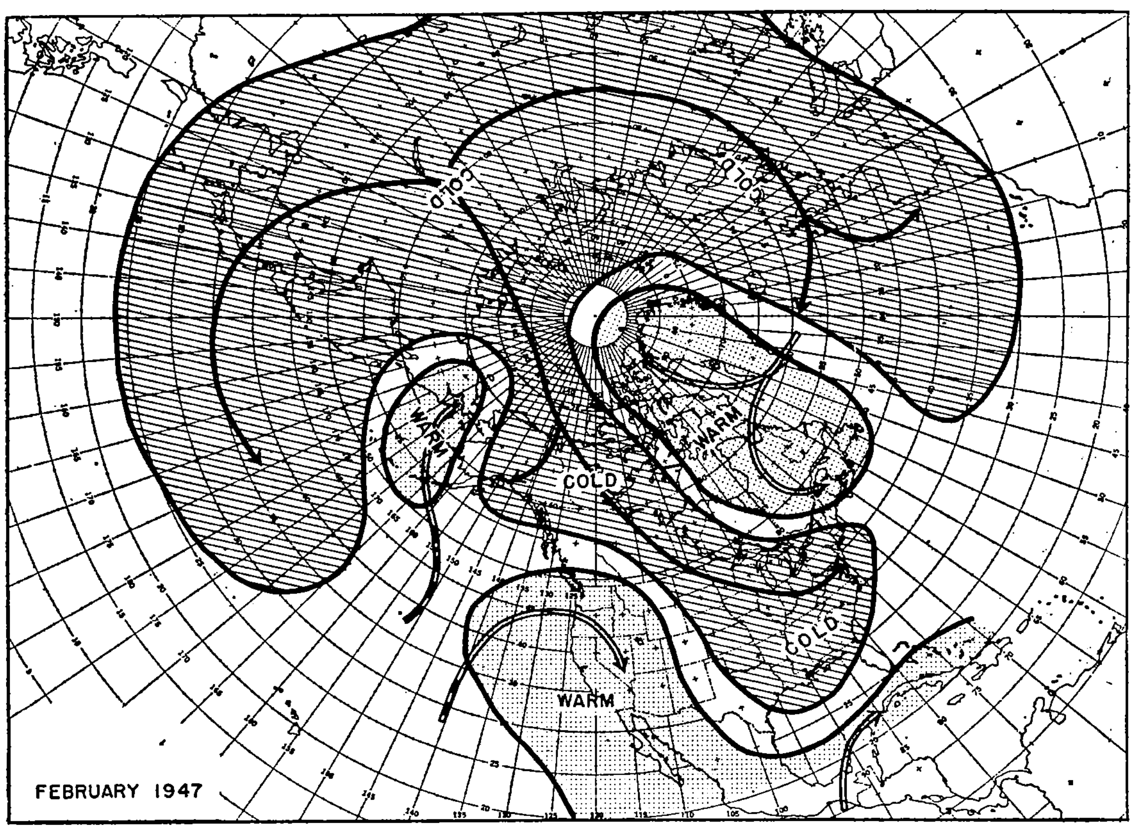

FIGURE 6.—General indicated temperature anomalies of the lower troposphere, 1,000 mb., to 700 mb., during February 1947. (Arrows indicate flow.)

United States was dominated by mild Pacific air masses, and the Polar Continental and Arctic anticyclones were trapped in northwest Canada. Most of Europe, on the other hand, was under the domination of the Siberian High, with the flow of warmer maritime air masses from the Atlantic unable to invade the continental areas to any appreciable extent. Thus blocked, maritime air masses were forced northward across Iceland, Greenland, and the Polar Basin. The weakness of the western cell of the Aleutian Low was associated with less than the normal amount of cold Siberian air flowing off the Asiatic coast.

In February (see Figures 2 and 4) a radically different circulation and weather regime took over. The confluence in the eastern Pacific and over eastern North America vanished, and with it went the fast westerlies over mid-latitudes. Cold continental air masses from Alaska and northwest Canada, no longer confined by the strong westerly circulation, broke through to eastern North America, producing severe cold as far south as Florida where much damage was done to the fruit crop. The cold Canadian air masses were soon replenished by new outbreaks from the Siberian High crossing the Polar Basin en route to eastern United States. The retrogression of the Siberian air into Europe, already begun in January, proceeded farther westward, giving Britain its severe cold and snowy continental regime. At the same time an increased flow of continental Siberian air took place off the Asiatic coast to feed a strengthened Aleutian Low. The strong easterly circulation over the Atlantic and eastern Canada made the Atlantic an important source region where the continental air masses of Eurasia were transformed into Polar Maritime masses and flowed into eastern Canada, producing a warm, wet condition there. In fact, during February warm fronts moving westward and southward across Labrador and the Great Lakes region were common features of the daily map analyses.

Some of the characteristic features of the general circulation during the Fall and Winter of 1946–47 are effectively shown by complete Northern Hemisphere indices of mass and circulation in Figure 7. In graph (a) the position of the subpolar minimum in the pressure profile (the latitude of separation between the sea level zonal westerlies and the polar easterlies) is plotted for overlapping monthly periods from October through March; the normal latitude of the zone of separation is indicated by the broken line. The sharp transition, chiefly between January and February, and the persistence of the abnormal southerly position of the separation through March is clearly shown. In 7 (b) the total anomaly of the mass of air over the Northern Hemisphere (from 20° N. latitude to the Pole) is shown. It appears that fluctuations in this quantity were not especially large (compared to fluctuations in other years), since the excess at high latitudes during February was in large part compensated by a deficit in lower latitudes (see profile inset of Figure 2). In 7 (c) the latitude of greatest strength of the zonal westerlies at sea level is compared with the normal. 7 (d) shows the speed of the zonal westerlies in the zone of maximum strength—i. e., at latitudes given in 7 (c). In spite of the decline in strength of the westerlies in temperate latitudes from January to February there was an *increase* in the net west-wind strength as the westerlies shifted southward. A still greater increase occurred in March.

Evolution of the Abnormal Circulation

The problem arises as to how an atmospheric circulation as radically anomalous as that of February (and March) 1947, could develop and maintain a quasi-stationary state

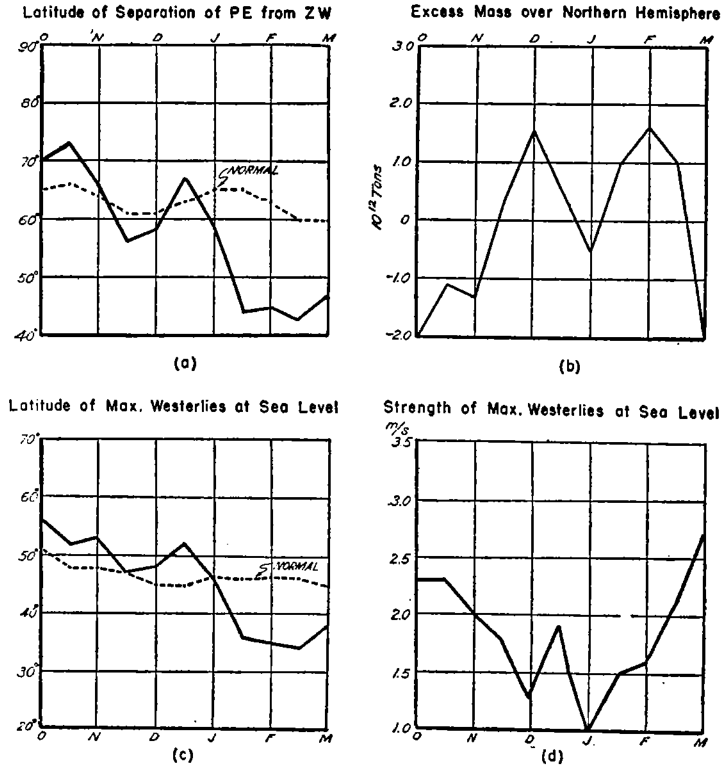

Figure 7.—Characteristic features of mass and general circulation indices over the entire Northern Hemisphere from October 1946 through March 1947.

over the Northern Hemisphere of the earth. What factors were associated with the tremendous growth, horizontally and vertically, of the polar cell of the atmospheric circulation and with the accompanying southward shift of the zonal westerlies and subtropical easterlies?

Some clues to this problem are offered by the comparison of Northern Hemisphere sea level pressure profiles and their anomalies for the period during the strong development of the intense polar cell. These are reproduced in Figure 8 for overlapping monthly means from mid-December through February. The shaded area measures the excess over normal of the mass of air which eventually contributed to the development of the strong polar cell and strong polar easterlies. In these profiles the motion and increase in area of the zone of excess mass can be traced in its slow movement northward from mid-latitudes during the December-January period to the polar regions during February. This anomaly of mass, computed for overlapping monthly periods from October to March for the area north of 47½° N. latitude, yields the results shown graphically in Figure 9 (d). From January to February the total mass of air north of 47½° N. latitude increased by over 4.63×10^{12} English tons. This is about 0.2 percent of the weight of the total mass of air in the Northern Hemisphere. As pointed out previously, this excess was compensated by a deficit of air (negative anomaly) in more southerly latitudes (see Figure 2). From the available aerological data it is not possible to obtain a similar graph for upper levels for the entire Northern Hemisphere. However, data from 0° westward to 180° W. longitude, and as far north as latitude 70° N.—slightly less than half of the hemisphere—are reliable. In order to compare the increases of mass observed aloft with those at sea level, it becomes necessary to compute the anomaly of mass for comparable areas at sea level and aloft. The appropriate sea-level graph is shown as a solid line in Figure 9 (c). Comparing this with 9 (d), for the entire hemisphere north

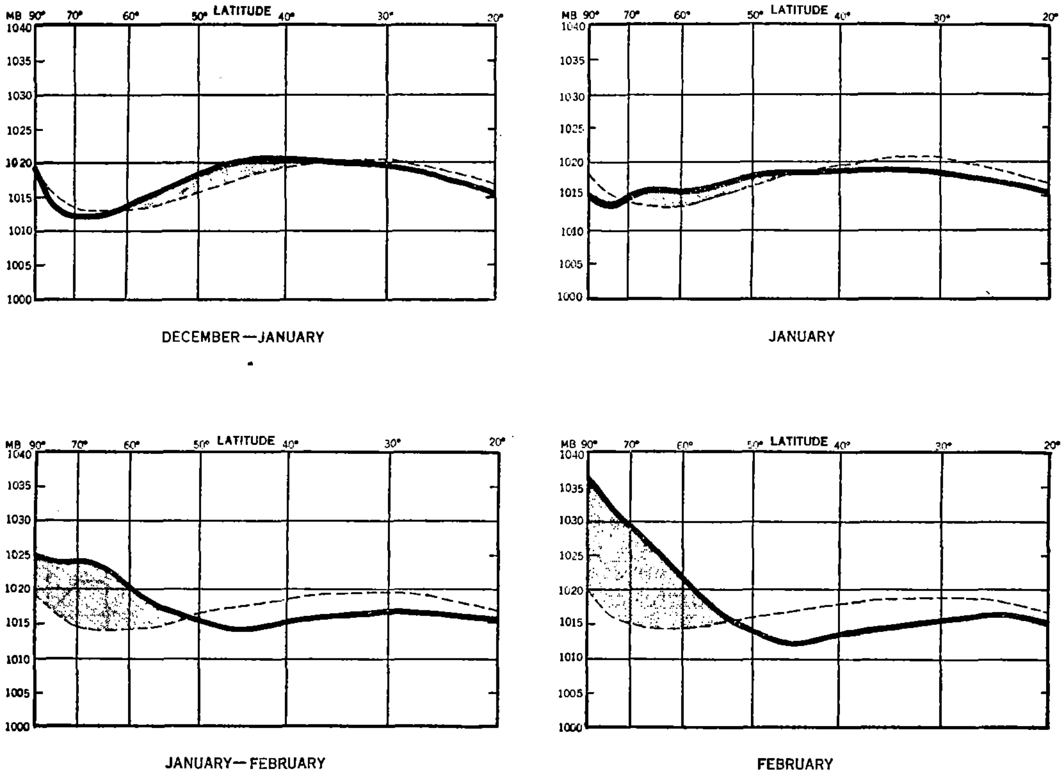

Figure 8.—Mean sea level pressure profiles, with normal profiles indicated by broken lines, for period from mid-December 1946 through February 1947. (Shaded areas indicate excess air mass anomaly.)

of 47½° N. latitude, it becomes apparent that the phenomenon of piling up of air over northern latitudes was circumpolar and not regional. For example, in February the excess over the restricted area was 1.6×10^{12} English tons, while for the hemisphere it was 5.5×10^{12} English tons. The percentage, 29 percent, is approximately the ratio of the two areas concerned.

To determine how the accumulation of mass was distributed with elevation, curves of the anomaly of mass at 700 mb. and 300 mb. were constructed from the available data. These curves are shown in Figure 9, parts (a) and (b). While reliable 700-mb. data were available between 0° and 180° W. longitude, 300-mb. data were available only for North America. Hence quantitative comparisons will be restricted to the 700-mb. and sea level data. However, it seems reasonable to infer from the general similarity of the 300- and 700-mb. curves that the piling up of air in high latitudes was an extremely deep phenomenon. Other evidence pointing to this conclusion will be presented later.

To find the contribution of the layer from 1,000 mb. to 700 mb. (roughly from sea level to 10,000 feet) to the sea-level excess, it is necessary not only to compute the anomaly of density of this layer but also to consider the effect of compressibility. An increase in density of the lower layers of the atmosphere may be due to increased weight (pressure) of air aloft compressing the lower layers, or to cooling processes. The effect of compressibility may be removed by the formula of Rossby [2]. This has been done in the computation of the broken curve in Figure 9 (c) which gives the contribution to the sea-level excess by the layer from 1,000 mb. to 700 mb. Some surprising and illuminating results are obtained when these two curves are compared. In the Fall and early Winter the pressure at sea level in northern latitudes increased chiefly because of the increased mass of air in the lower layers. In all probability this increase represents the radiational cooling of the imprisoned polar air masses discussed previously. However, during the period when the total mass above sea level had its greatest increase (January to February) the contribution of the layer from 1,000 mb. to 700 mb. actually *diminished.* This leads to the conclusion that the piling up of air in northern latitudes from January to February was chiefly due to accumulation of air above 700 mb. A complete investigation of the nature of this accumulation is beyond the scope of this paper and beyond the limits of available data. However, some analysis has been made of the monthly mean soundings obtained at Thule, Greenland. Two of these, for December 1946 and February 1947, are reproduced in Figure 10, along with the normal February sounding at Point Barrow, Alaska, for purposes of comparison. From the surface to about 8 km. the February sounding averages from 6 to 10 degrees warmer than the December sounding and indicates, as might be expected, a somewhat higher and colder stratosphere. The February warmth is associated with the diverted warm maritime Atlantic air (Figures 2 and 6). But in spite of the fact that it appears so much warmer than the December sounding, the pressures at station level are 23 mb. higher in February than in December. The contribution of 3-km. layers to the surface pressure differences was computed with the effect of compressibility removed, and the resulting figures are shown on the right of the elevation scale in Figure 10. From these it is clear that the lower 6 km. of the atmosphere contributed very strongly (by 15 mb.) toward making February surface pressures lower than December pressures; it is only at approximately 8 km. that the contributions become positive. If data permitted the analysis to extend throughout the entire height of the atmosphere over Thule, the sum of the numbers of the contribution column would total +23 mb. But adding them up to the 12-km. level indicates a contribution of −11 mb. It must therefore be concluded that above 12 km. there is contribution to the

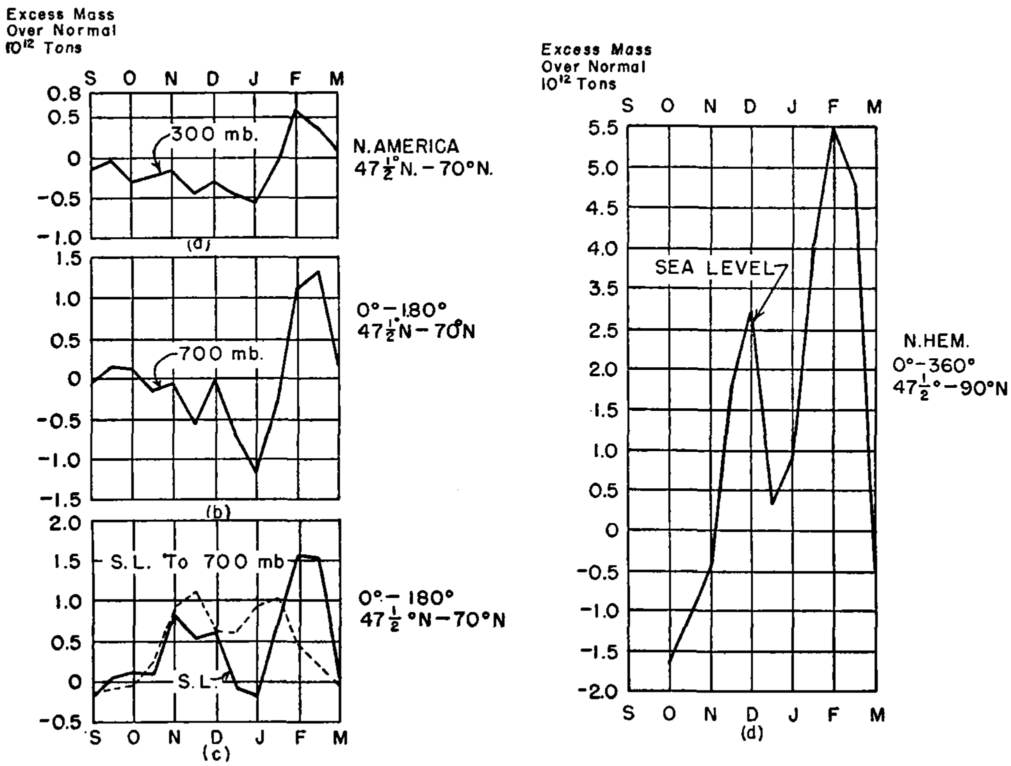

FIGURE 9.—Anomaly of mass from 47½° N. to 70° N. latitude, from September through March for (a) North America at the 300-mb. level; (b) from 0° to 180° W. longitude at the 700-mb. level; and (c) from 0° to 180° W. longitude for sea level (solid line) and for the layer from sea level to 700 mb. (d) shows anomalies of mass at sea level for the entire Northern Hemisphere north of 47½° N. latitude.

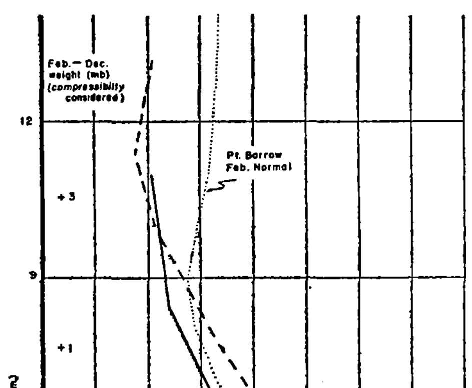

FIGURE 10.—Monthly mean soundings of the atmosphere over Thule, Greenland, for December 1946 and February 1947. Dotted line shows normal February sounding for Point Barrow, Alaska. Figures to the right of the elevation scale indicate the weight of 3-km. layers with the effect of compressibility removed.

extent of +34 mb. This does not mean that at 12 km. the difference in pressure of the two soundings is 34 mb. In fact, the difference is only 12 mb. But if a 12-mb. column of air were added to the 12-km. level of the December sounding, the increased column would compress the layers below it, and some of the air would sink below the 12-km. level. Hence, the net increase of pressure at 12 km. would finally be less than 12 mb. Compressibility computations show that a column of air at whose base the pressure is 34 mb. must be added to the December sounding to produce the differences of pressure at 12 km. and at sea level observed in the February sounding.

How could this addition have come about? The most obvious possibility is that in the higher, unobserved reaches of the stratospheric portions of the soundings of Figure 10, the February sounding was considerably colder and denser than the December sounding. This might account for the 34-mb. pressure difference. There is no possibility of definite proof or disproof, although the form of the observed curves in their uppermost portion hardly suggests this type of divergence of the two soundings. Another possibility, seemingly ridiculous at first glance, is that the height of the atmosphere—or better, the 1-mb. level—was appreciably greater over Thule in February than it was in December. This could account for the difference and appears to have no physically impossible consequences.

The principal question concerning the physical mechanism for the transfer of mass northward leads to study of the observed zonal wind speed profiles (Figure 11) as computed with the help of the geostrophic wind equation applied to overlapping monthly mean 700-mb. charts. The high-latitude strong westerlies of early Winter (through January) and the sharp displacement of the westerlies to southern latitudes in February and March

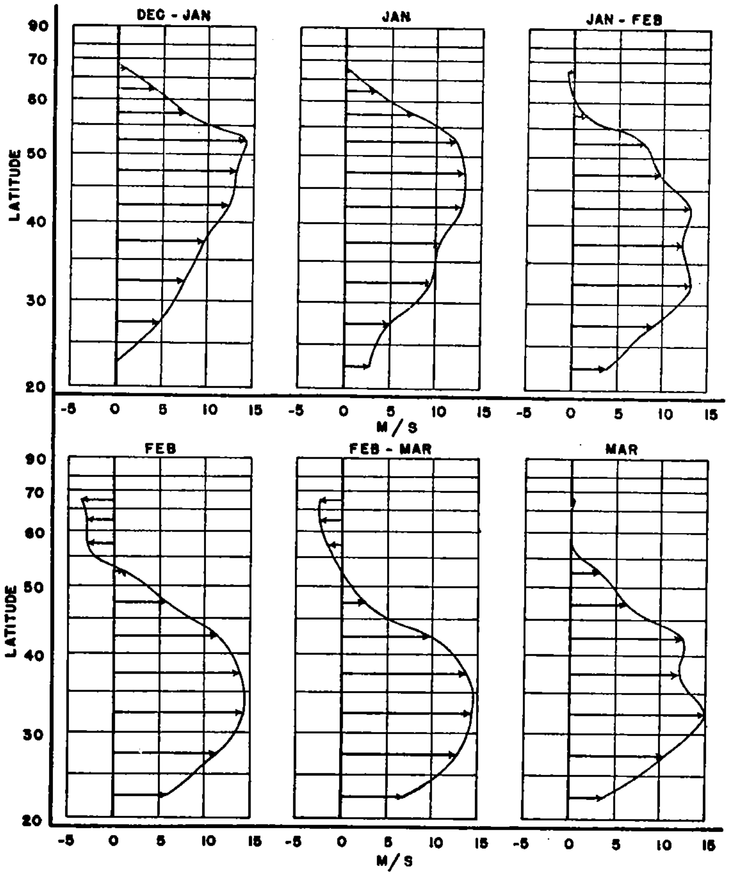

FIGURE 11.—Zonal wind speed profiles at 700 mb. (in units of meters per second) for the area from 0° to 180° W. longitude for overlapping monthly periods from mid-December 1946 through March 1947.

are clearly shown. This southward displacement does not appear as a gradual transition in spite of the overlapping character of the presentation of the data. Rather it appears that the southern maximum zonal speed took over at the expense of the northern. Thus in January a beginning of a secondary peak is indicated between 30° N. and 35° N. latitude. This peak grows to equal prominence with the higher-latitude peak from mid-January to mid-February, and then predominates in February. In March redevelopment of the northern maximum occurs.

Earlier it was pointed out that the strong high-latitude westerlies of January resulted from strong confluence over the eastern Pacific and in eastern North America. High-level charts show that confluence, detected at the 700-mb. level, extended through a thick layer of the atmosphere—at least to the tropopause. The peculiar pressure patterns favoring confluence (troughs north of ridges along the same meridian) changed radically during the first week of February and did not recover their earlier configuration. Consequently, with the cessation of confluence the speed of the high-level westerlies fell abruptly This diminution in the circumpolar vortex might well have led to northward flinging of the high-level air, owing to the lesser centrifugal force. This mechanism would be similar to the case treated by Rossby [3] in which he postulates piling up of air to the right of extensive, strong, supergradient wind currents; but in this case it is concluded that the reduction in velocity caused mass transfer to the left of the current. By use of this concept the following model for the development of the extensive polar cell of February can be evolved.

Confluence, strongly active during December and January, created strong upper-level westerlies which trapped polar air masses in their source regions. Adding to the imprisonment of Siberian air was the weakness of the Aleutian Low which tapped little cold air from the Siberian High. In February confluence abruptly ceased. The resulting sharp diminution of the high-latitude westerlies and the consequent lessening of centrifugal force resulted in a northward transport of high-level air from the circumpolar vortex. This high-level air was transported above the cake of cold Arctic air which, through radiational cooling during its long period of confinement, had been growing in extent. The greatly increased mass of air produced at the surface in high latitudes by this superimposition began to spread radially outward (southward) established the Polar Front farther south, and created new solenoidal fields for the development of strong westerlies far south of their normal latitudes.

To such a simple, perhaps oversimple, hypothesis there can be many objections. In the first place, the transport of a ring of air northward, as postulated, should lead to an *increased* west wind, owing to the principle of conservation of angular momentum. Increases indicated by this theory are never observed in the atmosphere [4], and the reasons generally given for this apparent disagreement with the angular momentum theory have to do with mixing processes (internal friction). But it must be borne in mind that the total magnitude of northward displacement necessary to effect an increase in mass of the order described here is probably very small. Moreover, as this air becomes superimposed upon the cake of stagnant Arctic air, a pressure distribution strongly opposing west winds is developed. The observed 700-mb. chart (Figure 4) shows, in fact, *east* winds at high latitudes.

Other objections which might be raised include the following:

1. Why were the flow patterns aloft so persistently favorable to confluence in December and January, and why did they change so radically in February? This is essentially the problem of the pattern of waves in the westerlies—a pattern which differs amazingly from year to year, and holds within it the key to the problem of long-range forecasting. The author does not know the answer.
2. Did extraterrestrial activity govern these circulation aberrations? The hypothesis advanced pictures the evolution of the circulation in the latter part of Winter in large part as a sequel of the earlier circulation. Hypotheses suggesting or, rather, indicating an extraterrestrial control would be appreciated; but up to the time of this writing no conclusive evidence has been brought forth.

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